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Shale elastic property relationships as a function of total organic carbon content using synthetic samples

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ABSTRACT

Understanding the main factors that control elastic properties of organic shale is crucial for exploration and successful gas production from unconventional reservoirs. Mechanical and dynamic elastic properties are important shale characteristics that are not yet well understood as there have been a limited number of investigations involving organic rich shale samples. Synthetic shale core samples whose clay mineralogy, non-clay mineral content and Total Organic Carbon (TOC) content are known can be used to study variations of elastic parameters in a controlled experimental environment including in-situ stress conditions.

A total of 17 synthetic shale samples with different mineral composition and TOC percentage were created for our investigations under isotropic stressed and unstressed conditions. Ultrasonic transducers were used to measure body wave velocities, which were then used to calculate the elastic properties of different shale samples. The results demonstrate that P- and S-wave velocities vary under isotropic stress conditions with respect to the TOC and clay mineral content. It is shown that isotropic stress significantly impacts velocity and the velocities of P- and S-waves are inversely proportional to TOC content. In addition, the increase in the TOC content reduced density and increased shale porosity. This study presents equations that allow us to estimate shale TOC content using compressional and shear wave velocities and density.

1. Introduction

Gas shale is a fine-grained, organic-rich sedimentary rock that is recognised to store natural gas trapped inside nano-size pores (Boyer et al., 2006). It is challenging to characterise unconventional natural gas reservoirs, because the elastic properties of shale rock vary significantly within and across such reservoirs due to various mineral composition and fabric anisotropy parameters exhibited by these organic rich shales (Altowairqi et al., 2015; Zhu et al., 2011). Presently our understanding of their dynamic and elastic behaviour is very limited, due to the low volume of variable organic shale samples available as well as the amount of time taken to test low-permeability samples. Experiments involving organic shale core samples can be found in a limited number of publications (Altowairqi et al., 2015; Altowairqi et al., 2013; Dewhurst et al., 1998; Dewhurst and Siggins, 2006; Dewhurst et al., 2011; Delle-Piane et al., 2011). One of the difficulties is that organic rich shales are chemically and mechanically unstable, due to the organised distribution of platy clay minerals (Zhu et al., 2011) and compliant organic materials (Vernik and Nur, 1992; Vernik and Liu, 1997; Sondergeld et al., 2000; Vernik and Milovac, 2011). There are suggestions in literature that it is not only the amount of clay or organics affecting the anisotropy in organic rich shales, but also the organic maturity of the shales (Sone and zoback, 2013; Sone, 2012). There are also many issues that are caused by shale anisotropy with respect to depth conversion for seismic exploration, amplitude variation with offset (AVO), imaging of structures in both seismic and crosshole tomography studies (Banik, 1984), and fluid identification (Sheriff, 2002). Anisotropy can indeed be a source of significant errors in estimation of the dynamic Poisson's Ratio (Thomsen, 1986).

Results of limited experiments that include stress control have reported that fabrics, the orientation of stress anisotropy with different fabric and fraction orientation influence the elastic properties of shale (Altowairqi et al., 2013; Delle-Piane et al., 2011; Dewhurst et al., 2011). Therefore, it is difficult to account for all the factors affecting the velocity and anisotropy of a real shale sample. In particular, factors including stress state, stress history, clay mineral content and TOC content are not widely reported (Altowairqi et al., 2015; Bohacs et al., 2005). Previous laboratory experiments

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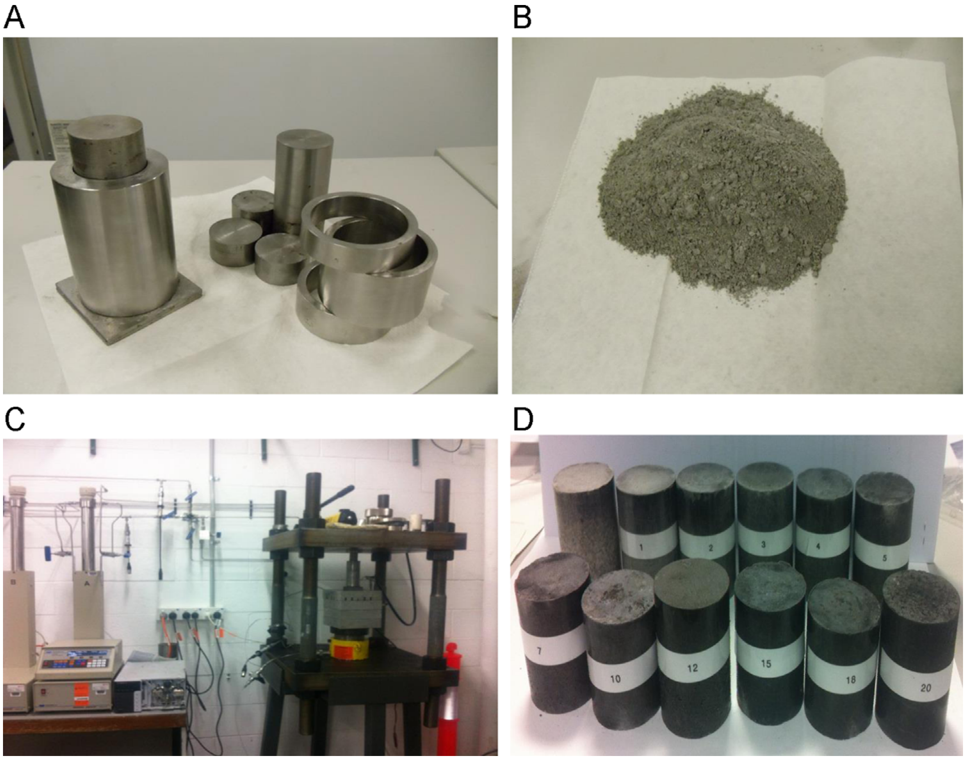

Fig.1. (A) Steel cylinder casts designed for high pressure use, (B) the mineral mix as a fine powder, (C) hydraulic compressor with different steel blocks and hydraulic pressure jack used to create synthetic shale, and (D) Synthetic shale core samples with different percentages of TOC from 0% to 20%.

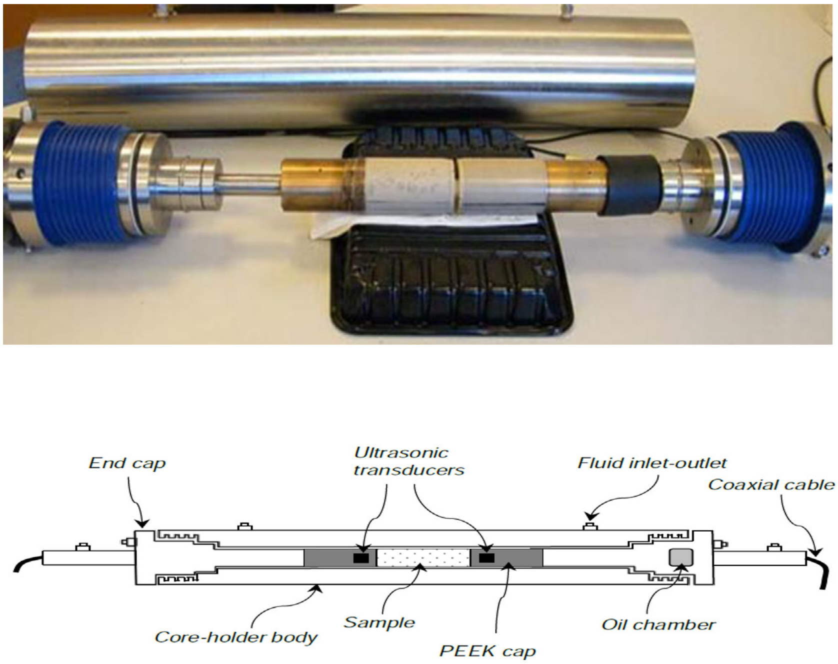

Fig. 2. View and schematic of core holder which was used for testing the ultrasonic wave velocities under stress.

have investigated the impacts of the stress, lithology and TOC content on wave velocities using real shale core samples from the Perth Basin (Altowairqi et al., 2015; 2013). The results showed that the velocities increased with the stress levels and the velocities decreased as the TOC percentage increased. In addition, other factors including TOC, clay minerals, porosity and density have an influence on the elastic wave velocities of organic shale (Altowairqi et al., 2013). Such experiments in testing real shale samples are difficult to control in terms of all the factors that affect the elastic and mechanical properties of real shale samples and are dependant on the sample quality. In contrast, synthetic shale samples provide us with the opportunity to conduct investigations in a fully controlled environment where variability of parameters is controlled by the user. We can thus produce core samples with a known percentage of clay minerals, non-clay minerals and TOC content under variable and/or in situ stress conditions. Such a system enables us to study the contribution of each of the factors independently. However, the process of creating the synthetic